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Dyslexia and Reading as Examples of Alternative Visual Strategies

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INTRODUCTION.

We offer evidence that ordinary readers and dyslexics differ systematically in the distribution of certain perceptual properties over the visual field. These differences are laid to alternative strategies of perception. Our supposition is that any ordinary person possesses a file of visual tactics and can switch between them, depending on the type of task to be performed and the strategy used in performance. Tactics as well as strategies evolve as a result of practice that carries task performance from the novice level to the expert level.

The notion of a task entails that certain regions in the perceptual sphere be more salient than others, weighted by usefulness to the task that is being set appetitively. So, in reading, vision is most salient; in piano-playing, audition and kinesthesia are most salient; and so on. This weighting of perception does not alter the content of the representations offered to perception. Such weighting can be called "attention"; and it is clearly a tactic in the appetitive or goal-setting process.

Appetition, accordingly, affects perception in two ways. One way is by the external loop through the motor system acting against the world. The other way is by a direct action on perception itself, differentially weighting different regions of perceptual sphere with respect to the representations offered. That is, progress to expert performance involves learning what to attend in perception as much as what to do in action.

Ordinarily, what is meant by "visual attention" is the setting of a narrow zone in the visual field wherein perception is clear and distinct. Experimentally this can be made to occur anywhere within about a 10 degree radius around the foveal region. Practically, however, it usually means centering the axis of gaze on a part of the image in which detail of form and change in the detail is important. But this view ignores the bulk of our use of vision when we are not reading.

For example, take a sports broadcaster reporting a football scirmmage. Twenty-two men are engaged in a play that usually takes but a few seconds. Yet the broadcaster not only tells who carried the ball, but who was blocked and by whom, who committed a penalizable move, and in general,provides a remarkable amount of information about the play. We must attribute to the reporter an attention in which the exact detail along the axis of gaze is not only mostly useless, but would distract from the more important patterns of action distributed over a fairly wide angle in the field of view. The reporter has learned the basic plays, and how they are embodied in configurations of the players prior to the action. And so he reads, more easily than most of us, the actual events as error with respect to what is predicted from the plan. In this way he uses prior knowledge to reduce how much information he needs to recount events in the scrimmage.

Without fussing about further refinement of this approach, we will identify two simple broad strategies of vision and call them the "scribe" mode and the "hunter" mode. In the scribe mode, attention is profoundly foveal, and objects rapidly become less clear and distinct as their angular distance from the fovea increases. In the hunter mode, attention is on the scene, and the gaze axis mainly sets a point in the scene as a kind of a center around which events of known character are expected. In short, if the visual task calls for high local detail at a narrow region of a relatively stationary or slowly changing arrangement of objects in the field of vision, a scribe strategy is chosen. If the task calls for ruleful relations between more widely spaced things, the hunter strategy is chosen. This is an example of two task-determined strategies between which the observer can switch.

The notion that what is attended is clear and distinct, while what is not loses saliency, raises the issue, wherein lies the loss of saliency? The demonstration below provides the basis for an argument.

N x VHNEK

If you fix and hold your gaze on the x, the N on the left seems relatively clear. The N on the right, imbedded among other letters, is not clear at all. (That this is not a function of left versus right in the visual field can be shown by turning the page upside down). The clarity of the solitary N on the left testifies that visual acuity is adequate at that angular distance from the fovea. Thus, the obscuring of the imbedded N has to be explained. The terminal letters of the group can be identified – the further one, surprisingly, is more definite than the nearer one. But it is as if the letters flanking the N prevent it from being assigned a form. This property has been termed "lateral masking" in the literature (e.g. Bouma,1970; Mackworth,1965; Townsend et al,1971).

Lateral masking increases in strength as the letters become more closely spaced or if the group is moved yet further out in the peripheral field. Another way of describing the impression of the letter string is that it has lost form and has become a texture, more or less in the sense of B. Julesz. One has the feeling that the perceived spatial order of the parts has been degraded while certain statistics of the image remain, so that there are distinct edges and corners, but where they lie with respect to each other and how they are connected is somehow obscured. That this is not a loss of information in representational processing can be shown by "demasking" the interior N. If the letter string is flashed tachistoscopically with any figure except N flashed at the same time at the fixation point, the masking of the N is quite strong. But, if an N of the same font, size, contrast, and spatial orientation is flashed at the fixation point simultaneously with the string, the interior N stands out.(Geiger and

Lettvin,1986). The same is true in varying degrees for all other upper-case letters, save the plain vertical bar, "I". In the steadily shown image, steadily attended at the fixation point, a quick small vertical movement of an imbedded laterally masked letter also demasks it.

What we suspected is that, among readers, the sharp increase of lateral masking with eccentricity of the letter string from the fixation point is a learned tactic. Since even a single letter, if more complex than a simple vertical bar, shows lateral masking between its parts, it is obviously subject to the same tactic. But is it a tactic or a built-in process in vision? Suppose someone is frozen to the hunter mode of seeing, would he show the same measures? Could these measures be changed by practise?

With tachistoscopically presented letters the shape of the decline in letter recognition with incresing lateral displacement – the Aubert-Foerster law (1857) – has been taken as a sturdy and primitive observation for over a century. No one seems to have noticed that the subjects were predominantly readers. As is shown by the experiments reported here, dyslexics have a different shape to the recognition/displacement curve in the peripheral visual field. And as is also shown, the shape can be changed by designed practise.

In lateral masking, the reduction of form to texture has an odd quality. There are "features",by which we mean those primitives used to characterize forms. Let us suppose, for the moment, that they are the "textons" which Julesz and Bergen (1983) use for their description of texture elements. In perceiving a form, we see these component elements connected in a particular arrangement or spatial sequence. The form has handedness, orientation, and is clear and distinct. In perceiving the same arrangement texturized, we see the same component elements, but cannot assign them that connecting order which determines a form. If this transition between an aggregate, described statistically, and an arrangement, described geometrically, can be simply governed, that accounts for one of the tactics by which appetition directly affects perception. There is a control on conversions between form and texture vision. This does not introduce content into the representations offered to perception, but only weights how they are processed in perception.

The notion of task-determined control of perception can be realized by such a scheme. Returning to the scribe/hunter paradigm, the scribe, whose interest is confined to a narrow angle in the field of vision, practicing to become expert, introduces as a result of practice a degenerative lateral masking outside that angle. He limits his attention to the fovea, which is engineered for highest acuity. The hunter, who is concerned with the distribution of possible events over a wide angle in the field of vision, introduces, under practice, lateral masking in the fovea to suppress the excess of form resolution there. Instead he uses the fovea to set a center around which he attends patterns of related change.

Common experience of driving in traffic testifies to the alternation between scribe and hunter states – instants when one glances at a road sign versus stretches when one is concerned with the ambient flow of cars. But this is anecdotal. A more careful experiment was done by George Sperling (personal communication) two decades ago. It had earlier been shown that foveal vision is somehow compromised during a saccade. Sperling's experiment was this: A strobe light is coupled to the eye movements of a subject sitting in a dark room. It is the sole illuminant and flashes only in the middle of a large saccade. The subject finds it impossible to read even a newspaper headline when its image falls on the fovea during a saccade. (He quickly learns how to center the text on the fovea at the instant of the flash). The headline is there, but has the same textural quality that is observed in the eccentric letter strings of the previous demonstration. What is interesting is the result that after the subject tries to read for about a quarter-hour under this abnormal lighting, quite suddenly his reading ability returns as if the foveal "suppression" had been switched off. Many sources provide evidence for the proposition that practiced performance involves not only a change in the course of action, but also a change in the perceptions guiding that course. These changes can be attributed to practised task-determined strategies, and such strategies are usually mutually exclusive. Ivo Kohler (1962) as well as Richard Held and Alan Hein (1958) give good illustrative examples. Our concern, however, has been with tactics, such as regional form-texture conversion within the visual field. These seem to us to be quite as important as general strategies, and equally susceptible of appetitive control.

EXPERIMENTS.

In order to show the differences in visual strategy between ordinary readers and dyslexics, we designed two tests. In one, we measured how recognition of single letters falls off in the visual field with increase of angular distance from the axis of gaze. In the other we used strings of letters rather than singlets to note differences in lateral masking as eccentricity increases away from the axis of gaze.

The First Test: Form-Resolving Field (FRF)

The form-resolving field (FRF) is that portion of the visual field in which forms, presented tachistoscopically, are recognized to one degree or another. We operationally defined the FRF in the following way: In a test flash (as described below under "methods") the displayed letters are presented at some fixed angular size and contrast against a background of fixed luminance. Once the flash duration is chosen for a subject it is held constant for the run of measurements. The displayed letters are changed with every flash, and their angular distance from the gaze axis can be varied. Two letters are exposed in each flash, one at the fixation point (the center of gaze), the other at some angular distance in the peripheral field. The two letters are never the same. Both are to be identified by the subject immediately after the presentation. When about twenty such exposures of different letter pairs have been delivered at one eccentricity, the eccentricity is changed and a new series of twenty is presented. After the tests in all eccentricities are finished we plot the percentage of correct identification of the peripheral letters as a function of eccentricity. This plot is the FRF. It is not a measure of acuity, as will be evident later. What is at issue is the recognition of form rather than the resolving power.

Aparatus and Stimuli: Three slide projectors were focussed from behind on a framed translucent diffusing screen 35 cm. long and 23 cm. high. Each projector was set to give a uniform illumination across the screen at 180 cd/sq.m. as measured at the front of the screen. The projectors were operated in a time sequence. At first a fixation point is presented (by projector I). Except during a test this slide is constantly on. In a test the shutter in front of projector I shuts as that in front of projector II opens for short interval, T_1, to present the

stimulus image. T_1 is followed by a second interval, T_2, when no projection plays on the screen. The stimulus duration is counted as the sum of T_1 and T_2. This sum is adjustable but never was longer than 10 ms. in the first test,(single letters to show the FRF), and it was 61 ms in the second test,(letter strings to show the effects of lateral masking). Following the interval T_2 the eraser goes on (projector III) for 2.5 seconds. In these tests the eraser consists of a blank lit screen. Following the eraser a new cycle starts after the subject reports.

No two letters on any slide were the same, and no two slides were the same. All eccentricities are given in terms of visual angle away from the fixation point.

Procedure: In the stimulus sequence the effective stimulus duration (from onset of the stimulus until the onset of the eraser) was adjustable in such a way that the best score of identification (at whatever eccentricity of the peripheral letter that gave the best score for the subject) lay just below 100%. This normalization procedure is best suited for form resolution since this normalizes sensitivity in form identification and not the sensitivity to contrast or lightness[1].

The stimulus exposure duration was set prior to the test itself. Once the best duration was determined for a subject it was fixed for that subject throughout the test at all eccentricities. After each stimulus presentation, the subjects reported what letters they had seen and which was at the fixation point, which in the periphery. The report was recorded and the next stimulus was given. Once all slides for all eccentricities had been presented, the percentage of correctlly identified letters at each eccentricity was determined.

The centering of the subject's gaze on the fixation point was visually monitored by the experimenter. This crude monitoring was sufficient, as some later instrumental verification has shown.

Subjects: All subjects were above 18 years old. All but two of them were completely unaware of the purpose of the tests until the testing was finished. Two groups were tested: ORDINARY READERS: This is a group of 10 ordinary readers (3 females and 7 males), all between 18 and 25 years of age with one exception. The subjects came from the general university-level student population. DYSLEXICS: This is a group of 10 dyslexics (2 females and 8 males) who did not have special tutoring within the last 3 years. They were between 20 and 58 years of age. All the dyslexics were diagnosed as such by their respective neurologists, psychologists and teachers. They all showed a normal level of comprehension of heard texts, but all had serious difficulties in reading.

Results of the Test: At the end of testing all the subjects, the scores of correct identification were gathered and averaged at each eccentricity for each separate group . These avereges are plotted in figure 1 to show the FRF's of the groups.

In general the FRF falls off with eccentricity from the center of gaze. However, there are obvious differences in the shape and the grading of the fall-off.

In the right hand side of figure 1 two curves are plotted; one for ordinary

[1] In another study we measured correct identification when stimuli exposure durations were equal for all subjects. The results were similar to the ones obtained with this normalisation, but were less distinct.

readers and one for the dyslexics . From these curves we see that ordinary readers and dyslexics are significantly different at all eccentricities except at 5 deg. (we have performed the ANOVA and t-tests). Therefore it is safe to say that these are two distinct groups under this test.

The differences between the dyslexics and the ordinary readers are two-fold. Dyslexics identify letters further in the periphery than ordinary readers do. Also, dyslexics identify letters better at 5 deg. eccentricity than they do nearer to the center under the conditions of this test (i.e. a letter at the center and the second one in the periphery). This is in contrast with ordinary readers who identify letters best at the center and have an FRF that falls off monotonically to the periphery.

As this test is a measure of the form-resolving field we are able to say that ordinary readers have a narrower FRF than dyslexics do. The shape of the FRF in dyslexics shows a peripherally displaced peak. That is, lateral masking occurs near the center of gaze, a peak of "best vision" shows up in the near periphery, and the FRF falls off shallowly with further eccentricity. In contrast, among ordinary readers the FRF falls off steeply, smoothly and monotonically with eccentricity from the center of gaze. The implications are that ordinary readers are able to discern forms (single or aggregates) best at the center of gaze (fovea), whereas dyslexics discern aggregates of forms best in near periphery but have lateral masking at the fovea.

The left side of figure 1 shows no significant difference between ordinary readers and dyslexics. The shape of the fall-off of identification on the left is

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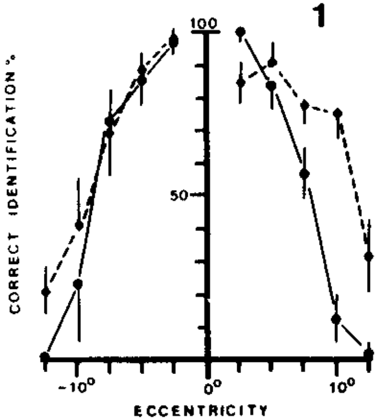

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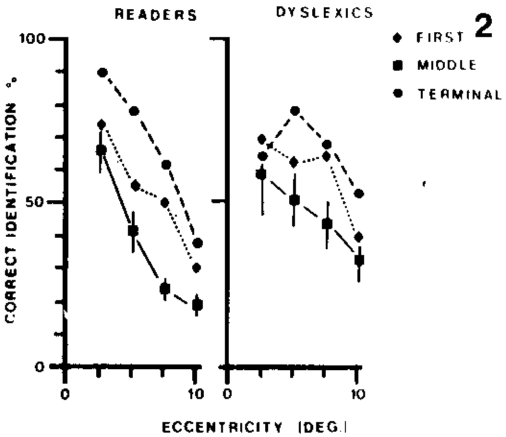

Figure 1. This figure displays the Form-Resolving Field (FRF) of ordinary readers ● and dyslexics ◆ . The measures are of % correct identifications of the letters at different eccentricities in the periphery. Vertical bars show the standard deviations. The scores for the letters presented at the same time at the fixation point are constant for all eccentricities (95%+or-4%) and are not given here.

Figure 2. The graphs show the strength of lateral masking as it varies with eccentricity. Ordinary readers are compared with dyslexics for correct identification of each letter in 3-letter strings that are presented at various eccentricities. The score at each locus along the string is given separately.

monotonic and steep for both groups. But the fall-off is steeper on the right for ordinary readers than on the left, and for dyslexics is clearly much shallower on the right than on the left. We attribute the differences between left and right in ordinary readers to the conventions of reading. (The basis for this guess is that two readers, for whom Hebrew is the native language, have shown the opposite asymmetry.)

These measures of the form-resolving field are well correlated with ability to read. The reader has a narrow FRF and a most clear vision around the center of gaze, as is needed for usual reading (we do not talk here about speed reading). On the other hand, not having that kind of FRF seems connected with difficulties in reading, as manifest in the dyslexics.

As also can be seen, what the FRF measures is certainly not what is ordinarily meant by "acuity". We do not hold that there is a difference in peripheral acuity between ordinary readers and dyslexics. Instead the difference lies in the perception of forms and not in the resolving power, as is suggested by the figure used in the introduction.We suspect that the differences are accountable by different tactics in the distribution of lateral masking. With single letters (not "I") the parts of a letter exert masking effects on each other. We can call this self-masking. If ordinary readers and dyslexics differ in FRF we propose to explain the difference in terms of distributions of lateral masking and self-masking.

Experiments on demasking (Geiger and Lettvin, 1986) have shown that only "complex" letters are demasked (letters comprised of more than a single bar). Single bars can not be demasked, while annuli are not easily masked. Thus it is reasonable to think of parts of a letter masking one another in much the same way as one letter laterally masks another.

We have been mentioning that the lateral masking at the center of gaze, such as occurs in dyslexics, looks similar to the lateral masking in the peripheral field had by ordinary readers. It remains for us to show how ordinary readers and dyslexics differ in lateral masking.

The Second Test: Lateral Masking Between Letters in a String.

The apparatus and methods are the same as for the FRF test. The differences lie in the nature of the stimuli and the duration of the stimulus-exposures. In this test four letters are presented in each stimulus (instead of two as in the previous test). One letter is at the fixation point and a string of three letters is in the periphery. All letters in each stimulus display are unlike each other. As in the previous experiment no two slides are alike. The strings in the periphery are displayed at various eccentricities in the various slides. Duration of the stimulus exposure was 61 ms. for all subjects.

Figure 2 presents the data by which to compare nine dyslexics with five ordinary readers. At each eccentricity of the string we give identification scores for each locus along the string (first, middle and terminal letters).

Some general properties of lateral masking are seen in the plots for ordinary readers: Masking increases with eccentricity; it is least effective for the terminal letter of the 3-letter strings and strongest for the middle letter. These properties are generally preserved for the dyslexics. However, there are some differences. a. Near the center the masking of the first, middle and last letters are about the same for dyslexics and for readers; but at 10 deg. eccentricity the middle letter is significantly less masked for dyslexics than for readers. b. The variance of the masking of the middle letter at string eccentricity of 10 deg. is larger for the dyslexics.

Learning Visual Strategies.

The results of the two kinds of test, as described above, suggest differences between readers and dyslexics in the distribution of certain perceptual processes over the visual field. The differences become magnified when severe dyslexics are examined, like the case of a severe dyslexic, whose initial FRF is shown in figures 3 and the initial test for lateral masking gave the plots graphed in figure 4a.

In figure 4a we show, for this severe dyslexic, the initial results of measuring lateral masking as a function of eccentricity. At 2.5 deg. eccentricity his score for all the letters in the string was almost zero. At the same time his score for the fixation letter also went to zero, as if the mutual lateral masking was extremely intense in the region around the center of gaze. With respect to this test he acts as if he had little or no form vision of aggregates in the fovea and parafovea. However at 7.5 deg. and 10 deg. he performed as if there were little lateral masking and little loss of letter recognition (as evident also from the initial FRF in figure 3). In this respect he was superior to readers in his peripheral vision. Such a case might raise the suspicion of some organic deficit in retinal function at the fovea were it not for the fact that so long as the background was blanked up to 5 deg. away from the center of gaze, he had

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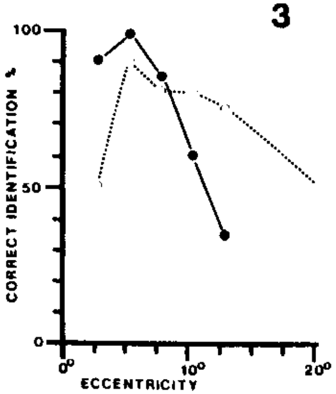

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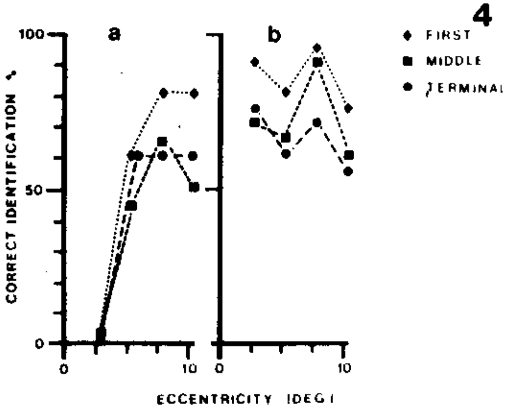


Figure 3: The initial plot of the FRF on a severe dyslexic is compared to the plot of the FRF taken four months later (solid line), after the practise described in the text.

Figure 4: a.) This graph of lateral masking against string eccentricity (done as in figure 2) plots the initial performance of the same severe dyslexic as in figure 3. b.) This graph shows the performance of the same subject four months later after the practise described in the text.

normal vision for single letters presented in the foveal field.

At this point, using the line of thought sketched in the introduction, we asked if it would be possible for this severe dyslexic to learn a new visual strategy that would permit him to read. Whatever set of visual strategies he possessed, if there were indeed such a set, excluded reading at and around the center of gaze. Thus no use of his existing set of strategies could be made in teaching him to read, because no reinforcement could occur in the foveal region. Since his FRF as well as his performance with the tests on lateral masking showed that his near peripheral vision had acuity adequate to reading, we decided to probe whether he could acquire a strategy for reading in the peripheral field of vision. If he could, and our tests measured something that correlated with visual strategy, then a retest after acquisition of the new strategy would show the change. Our hopes were based on the well-known phenomenon of speed-reading which implied that peripheral vision might be adequate to the task.

He was the first subject on which we tried the learning of a new strategy. The program we tried on him is described below in the protocols for training four dyslexics. It must be emphasized here that we were not and are not proposing a therapy. We are only testing the hypothesis that a new visual strategy can be learned if it does not compete in the domain of other firmly set strategies, i.e. it would not be advisable to train for foveal reading if the consequences of his existing strategies are that he masks in the fovea. He would than have no success by which to reinforce a new strategy by practise.

If, as we felt, the two tests, given above, measure some properties related to visual strategy, retesting after successful training, should it occur, would reflect the introduction of the new strategy.

He responded to the procedure, and, within four months went from a third grade reading level to about a tenth grade level. In practical terms he was able to take a job in which he had to read memos, bills of lading, and the like. When tested at the end of four months he showed the change in FRF given by the solid line in figure 3, and the change in lateral masking shown by figure 4b.. He can now make out letters in strings presented at 2.5 degrees eccentricity. His performance at that eccentricity is not as good as that of an ordinary reader or residual dyslexic, but is far better than in the initial test. Curiously, in now reporting the letters at that eccentricity, he stuttered (Geiger and Lettvin.,1987).

There is no point in describing further what the pictures make clear, and so we will go on to lay out the general method for testing the hypothesis.

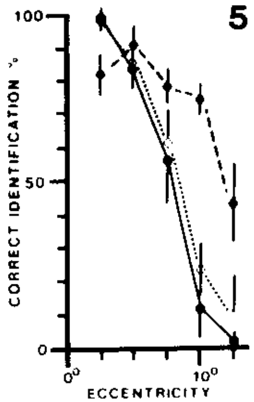
We asked four of the dyslexics (part of the group of 10 and including the severe dyslexic just described) to participate in a program aimed at their learning a new strategy. After we characterized each of the 4 subjects with the two tests, we advised them to devote two hours every day to the performance of novel, direct, small-scale, hand-eye coordination tasks such as drawing, painting, clay-molding, model-building, etc.. The rationale for this practise comes from experiments performed by Held and Gotlieb (1957), Held and Hein (1957) and remarks by Helmholtz (1867) on how a person shifts spatial localization after viewing his hand through a prism. The general idea was to provide visual perception with a new space of operation as defined by the new tasks.

Along with this practise the subjects were to try reading through a window in the peripheral field. A sheet lay over the text to be read. It could be transparent and colored, or translucent, or opaque. On it lay a fixation point or mark. At the right of that mark a window was neatly cut to a size somewhat larger than the length and height of a long word in the text. The distance from the fixation point to the center of the window was set individually for each subject by using the eccentricity of the peak of the FRF and the eccentricity at which there was a drop in lateral masking of the middle letter in a string.

When the subjects intended to read they were to lay the window over the desired word or words in the text while gazing at the fixation point and try to read what lay in the window. Keeping gaze on the fixation point they then shifted the sheet so that the window lay over the next word, and so on. In this way the words in the window might be seen as form rather than texture, without interference from the ambience.

After a few months (2.5–4) with this combined practice we again measured the FRF curves for each of the four subjects. We measured the lateral masking curves afterwards on only the severe dyslexic described above. We also inquired about, but did not measure, their reading skills. Figure 5 shows the averaged FRF for the four subjects before and after the practice term. For comparison, the curve for ordinary readers (from figure 1) is also displayed.

We should remark that the four subjects were not chosen by us. They were the only candidates among the 10 original subjects who could afford the time to practise daily. We did not instruct or guide the subjects more then by occasional telephone conversation.



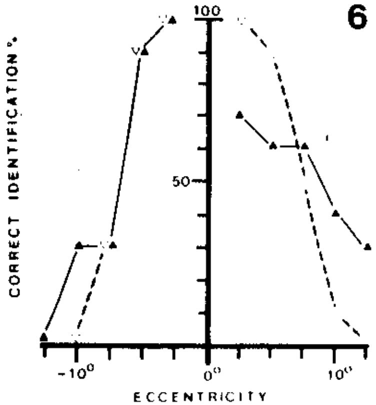


Figure 5. Graphed here is the effect of learning and practicing a new strategy. Plots of the FRF are averaged for a.) ordinary readers ● (taken from figure 2) ; b.) four dyslexics ◆ prior to the practise described in the text; c.)the same four dyslexics after that practise ◇ . The bars measure standard deviation.

Figure 6. Two strategies in one subject are measured within a few hours interval. One FRF was taken when he was in an alert phase (mostly in the morning) ▽ . The other FRF was taken 6 hours later when he was in a tired phase ▲ .

As seen in figure 5 there is a significant shift of the FRF from before practice to after practice. The shift is toward the FRF of ordinary readers. Ordinary readers do not vary significantly in FRF over time although we measured some over periods of 2 years and longer.

In general the reading performance of all the four improved much. The reading score of one went from 3rd grade before practice to 10th grade after practice. Another subject went from hardly reading at all (about 2nd grade) to reading fluently for half an hour at a time (difficult to estimate grade level). Another went from spells of slow reading for five minutes at a time to spells of reading fluently for hours at a time (So he reported). The fourth initially could only skim fast (like speed reading) with many errors. He had no ability to read slowly and with care. After the course of practise he was able to read "word by word" as well as by skimming.

Three of the four stopped practising after they had achieved some skill, and fairly quickly regressed in their ability ro read. This change was also reflected in their FRF's.

An Unusual Case. As a final note we want to describe an unusual case in some detail. This subject is a male 30 years of age. He has the peculiar complaint that while he can read facilely when he is "alert", he is unable to read or reads with great difficulty when he is "tired". When he is extremely tired he is able to "speed read" or skim a newspaper with good comprehension of the text, but he is unable to read in a "usual" way.

We interviewed him and tested him in two of his "phases", the alert one (mostly occurring in the mornings) and the tired one (in the same afternoons). We did not test him in the extremely tired phase.

When he was in the tired phase he appeared to be markedly dyslexic. He had high level of comprehension and intelligence. He seemed generally alert in his tired phase and without optical defects, but could hardly read. In the alert phase his reading was good for long spells of time (over an hour), with the usual speed of reading and with only an occasional stumble over an unfamiliar long word every now and then.

The measures of his FRF in these two phases are shown in figure 6. On the right side of the figure, one of the plots matches nicely the FRF of ordinary readers. These data were taken when he was in the alert phase. The other plot was taken when he was in his tired phase. It falls off shallowly with eccentricity and so extends further into the peripheral field. It resembles that of the dyslexics. On the left side of figure 6 the differences in the plots are small although a slight extension of the FRF into the periphery is evident for the tired phase.

Figure 6 shows a clear relation between measures of the FRF and the task-competence reported by the subject. In the light of his subjectively distinct states we can suppose him to be a conditional dyslexic whose states can be told by objective testing. He switches between these states for some not very obvious reason. In the tired state he is not fatigued—he uses the term to describe only his inability to read; otherwise he is alert and competent. That this is not a problem of acuity is driven home by the fact that these states are in the same individual. If his acuity is improved for peripheral vision, can the same change in optics worsen his foveal acuity, if one supposes that his physical optics have somehow altered? Alternatively, can one suppose that his retina has changed its connectivity somehow? Has he changed his linguistic ability? If so, what tests could be used to distinguish his clearly reported states? Has he altered the anatomical connections in his brain?

After we had made our measurements on this subject and explained to him our notion of task determined strategies, he succeeded in teaching himself to use the wide field (dyslexics') strategy when he was alert (in the morning). He did this because he knew that creative art work was easier for him when he was tired. When he needed to do creative work while he was alert he now could swicth voluntarily to the tired mode. The reverse shift, from being in the tired mode (wide FRF) to alert mode (narrow FRF), he is still unable to do. .

CONCLUSIONS.

We have presented evidence for the existence of alternative states or strategies in visual perception. These strategies can be tested by measuring recognition of figures or letters as a function of eccentricity from the gaze axis. They are also tested by measuring the strength of lateral masking as a function of the same eccentricity. By both these sorts of tests there are marked differences between ordinary readers and dyslexics in the peripheral field of vision. These differences cannot be laid to changes in visual acuity between subjects for two reasons: first, they can be altered by certain kinds of practise; second, they can be demonstrated in the same subject (one case) at different times of the same day.

In the strategy of the ordinary reader, best vision is around the axis of gaze. Lateral masking increases steeply with eccentricity from the gaze axis as does loss of letter recognition. In the visual strategy of the dyslexic there is masking around the center of gaze and best vision occurs a few degrees to the right of the gaze axis (if the language is English). Loss of letter recognition beyond that peak increases less steeply than for ordinary readers.

A dyslexic can be trained to read in the peripheral field of vision. This training does not challenge a prior strategy which masks letter strings in the foveal region. (Such masking does not allow that reinforcement needed to practise the foveal seeing of letter strings). When he is practised in reading by peripheral vision, the test signs of his visual strategy, when plotted, approach the plots found for ordinary readers.

The training of reading in the peripheral field is not to be construed as a therapy. It was done to probe the hypothesis that task-determined visual strategies can be learned, and that the presence of a new strategy can be detected by testing. While a therapy may possibly be based on this demonstration and the reasoning that led to it, we emphasize again that the demonstration was meant only to test a notion, not to cure a disorder.

REFERENCES.

Aubert, H. and Foerster, (1857) Beitraege zur Kenntniss des indirecten

Sehens. Graefes Archiv fuer Ophthalmologie 3(2), 1-47.

Bouma, H. (1970). Interaction Effects in Parafoveal Letter Recognition. Nature 226, 177-8.

Geiger, G. and Lettvin, J.Y. (1986). Enhancing the Perception of Form in Peripheral Vision. Perception 15, 119-130.

Geiger, G. and Lettvin, J.Y. (1987). Peripheral Vision in Persons with Dyslexia. N. Engl. J. Med. 316, 1238-43.

Held, R. and Gottlieb, N. (1958). Technique for Studying Adaptation to Disarranged Hand-Eye Coordination. Perceptual and Motor Skills 8, 83-86.

Held, R. and Hein, A.V. (1958). Adaptation of Disarranged Hand-Eye Co-ordination Contingent Upon Re-Afferent Stimulation. Perceptual and Motor Skills 8, 87-90.

Helmholtz,H.v. (1867). Handbuch der Physiologischen Optik. Vol.lll Leipzig; Leopold Voss.

Julesz,B. and Bergen,J.R. (1983). Textones, the Fundamental Elements in Preattentive Vision and Perception of Texture. Bell System Tech. J. 62, 1619-45.

Kohler, I. (1962). Experiments with Goggles. Sci. Am. 206, 62-72.

Mackworth, N.H. (1965). Visual Noise causes Tunnel Vision. Psychonomic Sci. 3, 67-8.

Townsend,J.T., Taylor,S.G. and Brown,D.R. (1971). Lateral Masking for Letters with Unlimited Viewing Time. Percep and Psychophysics 10, 375-8.